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(71) Applicants:
 • **Canon Sales Co., Inc.**
Minato-ku, Tokyo 108-0073 (JP)
 • **Semiconductor Process Laboratory Co., Ltd.**
Minato-ku, Tokyo 108-0075 (JP)

(72) Inventors:
 • **Ikakura, Hiroshi**
Minato-ku, Tokyo 108-0073 (JP)
 • **Nishikawa, Shunji**
Minato-ku, Tokyo 108-0073 (JP)
 • **Tokumasu, Noboru**
2-13-29 Konan, Minato-ku, Tokyo 108-0075 (JP)
 • **Azumi, Takayoshi**
2-13-29 Konan, Minato-ku, Tokyo 108-0075 (JP)

(74) Representative: **Schwabe - Sandmair - Marx**
Stuntzstrasse 16
81677 München (DE)

(54) **Method for modifying the surface of a substrate on which an insulating film is to be formed**

(57) Disclosed is a method for modifying a film-forming surface of a substrate, which is capable removing a base surface dependency in forming a film on the film-forming surface (12a) of the substrate (102) prior to formation of a film (13) by a thermal CVD method using a reactant gas containing an ozone-containing gas containing ozone (O₃) in oxygen (O₂) and Tetra-Ethyl-Or-

tho-Silicate. The method comprises the step of modifying the film-forming surface (12a) of the substrate (102) by allowing any one of ammonia, hydrazine, an amine, gases thereof and aqueous solutions thereof to contact with the surface (12a) of the substrate (102) before forming an insulating film (13) on the surface (12a) of the substrate (102).

FIG. 3A

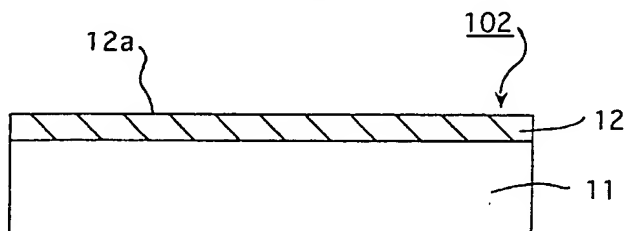


FIG. 3B

Surface Modification Treatment by Modification
Substances Containing Active Nitrogen

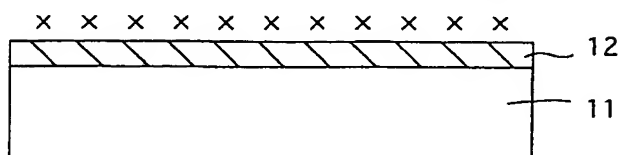
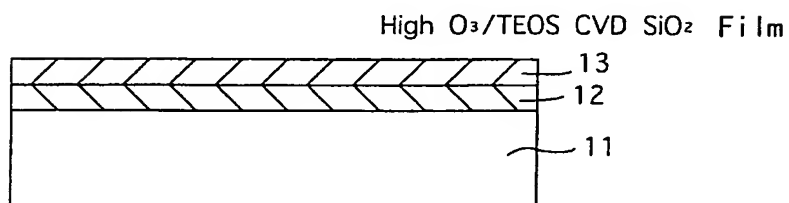


FIG. 3C



Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to a method for modifying a film-forming surface of a substrate (hereinafter referred to as a base), which is capable of improving a base surface dependency to a film formation on the base, prior to the formation of the film by a thermal CVD (Chemical Vapor Deposition) method using a reactant gas (hereinafter referred to as "O₃/TEOS reactant gas") containing an ozone-containing gas containing ozone (O₃) in oxygen (O) and tetra-ethyl-ortho-silicate (TEOS), and a manufacturing method for a semiconductor device using the same.

[0002] Here, the base surface dependency means that when an insulating film is formed on the surface of the base particularly by use of O₃/TEOS reactant gas, film formation rates differ depending on a difference of substances constituting the surface of the base exposed or the shapes of an acute angle portion and obtuse angle portion in concave and convex portions, or the surface of the insulating film is not flat due to an occurrence of fine unevenness on the formed insulating film, as shown in FIG. 1.

2. Description of the Prior Art

[0003] With recent progress in very high integration and multilayered wiring of semiconductor devices, a demand has been made for development of a technique for forming an insulating film, which is excellent in flatness, embedment of a concavity (hereinafter referred to as concavity embedment) and step coverage, and controls penetration of moisture and impurities. As the technologies for forming the insulating film that meets the above demand, a CVD method using an O₃/TEOS reactant gas has been attracting attention.

[0004] In the case where a film is formed by the CVD method using the O₃/TEOS reactant gas, as a concentration of O₃ is higher, a film with a higher quality can be obtained.

[0005] On the other hand, the state of the film thus formed strongly depends on the state of the surface of the base. The effect of the base surface dependency on the state of the surface of the base is not observed under a film formation condition where the concentration of O₃ is low, however, the effect thereof clearly appears under a film formation condition where the concentration of O₃ is high.

[0006] It should be noted that the O₃/TEOS reactant gas with a high concentration of O₃ and a silicon dioxide (SiO₂) film formed by the CVD method using this reactant gas are hereinafter referred to as a High O₃/TEOS reactant gas and a High O₃/TEOS CVD SiO₂ film, respectively. Furthermore, the O₃/TEOS reactant gas with a low concentration of O₃ and the silicon dioxide film formed by the CVD method using this reactant gas are hereinafter referred to as a Low O₃/TEOS reactant gas and a Low O₃/TEOS CVD SiO₂ film, respectively. Still furthermore, the silicon dioxide film formed by the CVD method using the O₃/TEOS reactant gas of any concentration of O₃ is hereinafter simply referred to as an O₃/TEOS CVD SiO₂ film.

[0007] FIG. 1 is a cross-sectional view showing abnormal growth of a film due to the effects of the base surface dependency.

[0008] As is shown in FIG. 1, a base surface dependency on the surface of the substrate 101 on which a film is to be formed (hereinafter referred to as a film-forming substrate) influences the surface of a High O₃/TEOS CVD SiO₂ film 4, causing the surface of the film 4 to be uneven. At the same time, voids occur in the High O₃/TEOS CVD SiO₂ film 4. It should be noted that the film-forming substrate 101 is composed of a semiconductor substrate 1, a base insulating film 2 formed thereon and wirings 3a and 3b formed on the base insulating film 2.

[0009] The methods shown in FIGS. 2A to 2D have heretofore been employed in order to remove the base surface dependency. The same elements as those shown in FIG. 1 are denoted by the same reference numerals.

[0010] The methods are:

- (i) the one for irradiating the film-forming surface of the substrate 101 with plasma (FIG. 2A);
- (ii) the one for covering the film-forming surface of the substrate 101 with a plasma CVD SiO₂ film 5 (FIG. 2B);
- (iii) the one forming a Low O₃/TEOS CVD SiO₂ film 6 as the base before forming the High O₃/TEOS CVD SiO₂ film (FIG. 2C); and
- (iv) the one for forming the Low O₃/TEOS CVD SiO₂ film 6 having thin thickness, irradiating the surface thereof with plasma, followed by forming the High O₃/TEOS CVD SiO₂ film (FIG. 2D). It should be noted that the above methods (iii) and (iv) use a double-layer composed of the Low O₃/TEOS CVD SiO₂ film 6 and the High O₃/TEOS CVD SiO₂ film.

[0011] However, each of the conventional methods for modifying the film-forming surface of the substrate as given

in above (i) to (iv) has the following problems, respectively.

(i) In the method using plasma irradiation, the conditions under which the effects of controlling the base surface dependency appears are not uniform. Accordingly, unification or standardization of the modification conditions by plasma irradiation cannot be achieved in all kinds of the film-forming surfaces of the substrates, but optimization is required as occasion demands. Furthermore, this method additionally requires a plasma enhanced CVD apparatus for the plasma irradiation.

(ii) In the modifying method by covering the film-forming surface of the substrate with the plasma CVD SiO₂ film 5, the plasma CVD SiO₂ film 5 which is very compatible with the High O₃/TEOS CVD SiO₂ film may be obtained depending on the conditions for film formation by the plasma enhanced CVD method. Accordingly, using the plasma CVD SiO₂ film to cover the film-forming surface of the substrate, the High O₃/TEOS CVD SiO₂ film of excellent quality can be obtained. However, the plasma CVD SiO₂ film 5 is intrinsically poor in step coverage, and therefore the plasma CVD SiO₂ film 5 is not suitable for a micronized pattern. Fire, the plasma enhanced CVD apparatus is additionally required for plasma irradiation.

(iii) In the method of covering the film-forming surface of the substrate with the Low O₃/TEOS CVD SiO₂ film 6, the Low O₃/TEOS CVD SiO₂ film 6 is very compatible with the High O₃/TEOS CVD SiO₂ film, and the base surface dependency can be removed by covering the film-forming surface of the substrate with the Low O₃/TEOS CVD SiO₂ film 6. However, the Low O₃/TEOS CVD SiO₂ film 6 has isotropic properties and a thickness of at least 100 nm is necessary as the base in this case. Therefore, the Low O₃/TEOS CVD SiO₂ film 6 is not suitable for the micronized pattern.

On the other hand, another method for removing the dependency on the film-forming surface of the substrate has also been attempted. This method uses the O₃/TEOS CVD SiO₂ film, instead of the Low O₃/TEOS CVD SiO₂ film 6, as the base under low pressure. However, using the O₃/TEOS CVD SiO₂ film under low pressure is substantially the same as using the Low O₃/TEOS CVD SiO₂ film 6. Accordingly, using the O₃/TEOS CVD SiO₂ film under low pressure is not suitable for the micronized pattern for the same reason that applies to the Low O₃/TEOS CVD SiO₂ film 6.

Furthermore, the O₃/TEOS CVD SiO₂ film under a Low O₃ atmosphere and low pressure is inferior to the High O₃/TEOS CVD SiO₂ film in quality.

(iv) The method of covering by the Low O₃/TEOS CVD SiO₂ film 6 and irradiating the surface of the film with plasma is not suitable for the micronized pattern and makes manufacturing steps of the semiconductor device complicated.

[0012] Thus, all in all, the conventional methods for modifying a surface of a base are not so suitable for covering a narrow and deep concavity. Accordingly, the high integration of the semiconductor devices have been desired nowadays, and formations of an interlayer insulating film and a cover insulating film with a high quality by using a film forming method by the CVD method have been desired. In particular, covering the narrow and deep concavity has been desired.

SUMMARY OF THE INVENTION

[0013] An object of the present invention is to provide a method for modifying a film-forming surface of a substrate, which is capable of almost completely removing a base surface dependency to a film formation on the film-forming substrate by using very simple technologies, and a method of manufacturing a semiconductor device using the same.

[0014] In the method of the present invention of modifying the film-forming surface of the substrate, the film-forming surface of the substrate is allowed to contact with ammonia, hydrazine, an amine or an amino compound, gaseous derivatives thereof or aqueous solutions thereof, thus modifying the film-forming surface of the substrate.

[0015] To be more specific, the foregoing substances used for modifying the film-forming surface of the substrate (hereinafter referred to as "modification substances") have characteristics of having an active nitrogen and a hydrophilic nature, and thus it can be considered that the modification substances have a function to dehydrate the film-forming surface of the substrate by reacting with a hydroxyl radical or H₂O bound to silicon in the film-forming surface of the substrate. With this function, a dangling bond of silicon forming the film-forming surface of the substrate can be terminated in NH₄O⁻ or NH₂-base. The base surface dependency on the film-forming surface of the substrate for the film to be formed on the film-forming substrate can be deleted. In particular, since a neutral gas is used as the modification substance, the modification substance covers a narrow and deep concavity, so that the base surface dependency of the surface of the concavity can be deleted.

[0016] Accordingly, when a film is formed on the film-forming surface of the substrate, from which the base surface dependency was deleted, by a thermal CVD method, it is possible to obtain an insulating film or a cover film with an excellent quality, which is free from roughness of its surface or a void without lowering a film formation rate. Additionally, almost complete embedment of the narrow and deep concavity can be achieved.

BRIEF DESCRIPTION OF THE DRAWING

[0017] For a more complete understanding of the present invention and the advantages thereof, reference is now made to the following description taken in conjunction with the accompanying drawings, in which:

- 5 FIG. 1 is a cross-sectional view showing a situation of a conventional semiconductor device in which High O_3 /TEOS CVD SiO_2 film is formed before a modification treatment for a film-forming surface of a substrate;
 FIGS. 2A to 2D are cross-sectional views, each of which shows a conventional method for modifying a film-forming surface of a substrate;
 10 FIGS. 3A to 3C are cross-sectional views showing a method for modifying a film-forming surface of a substrate according to an embodiment of the present invention;
 FIGS. 4A to 4E are drawings showing the principle of the method for modifying the film-forming surface of the substrate according to the embodiments of the present invention;
 FIG. 5 is a cross-sectional view showing a first embodiment of the embodiment, in which the method for modifying the film-forming surface of the substrate of the present invention is applied to a film-forming surface of a substrate which has wirings;
 15 FIG. 6 is a cross-sectional view showing a second embodiment of the present invention, in which the method for modifying the film-forming surface of the substrate is applied to a film-forming surface of a substrate having a trench;
 FIG. 7 is a cross-sectional view showing a comparative example of FIG. 6;
 20 FIGS. 8A and 8B are side views showing modification treatment systems used in the method for modifying the film-forming surface of a substrate according to the embodiments of the present invention;
 FIG. 9 is a side view showing a cold wall type modification treatment/film formation apparatus used in the method for modifying a film-forming surface of a substrate thereon according to the embodiment of the present invention;
 and
 25 FIGS. 10A and 10B are side views, each of which shows hot wall type modification treatment/film formation apparatus used in the method for modifying the film-forming surface of the substrate according to the embodiments of the present invention, and FIG. 10A shows a horizontal system and FIG. 10B shows a vertical system, respectively.

30 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

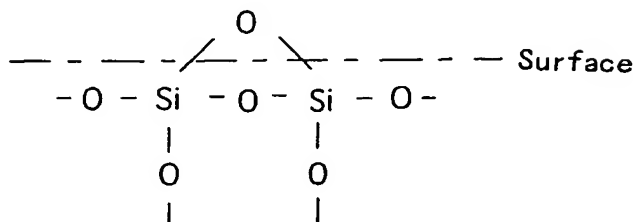
[0018] Embodiments of the present invention will be described with reference to the accompanying drawings.

(The process until the present invention was made)

- 35 [0019] First, the process until the present invention was made and the principle of the present invention will be described.
- [0020] When an insulating film is formed by a CVD method on a surface of an SiO_2 film, Si_3N_4 film or the like composing a film-forming substrate, a state of the insulating film strongly depends on a state of the surface of an SiO_2 film, Si_3N_4 film or the like. That is, the insulating film to be formed shows abnormal growth. For example, with reference to the SiO_2 film, Si_3N_4 film and the like, which are formed by various manufacturing method, when an insulating film is formed by a CVD method on an insulating film as the base film formed by any of a plasma CVD method, a thermal oxide method, and a reduced pressure thermal CVD method, which is not compatible with an O_3 /TEOS reactant gas, the state of the surface of the base film strongly effects the insulating film formed thereon, so as to cause a porous and rough surface of the insulating film and reduction of a film formation rate for the insulating film.
- 45 [0021] In air, which means, in a clean room having humidity, the surfaces of these SiO_2 films sometimes exhibit hydration state, which is caused by adsorption of H_2O or an OH radical, by being left in the clean room. However, it is assumed that the hydration is a factor, in formation of a High O_3 /TEOS NSG film (an NSG film means an SiO_2 film which does not contain impurities such as phosphorus, boron and the like), which prevents the smooth and uniform adsorption of an intermediate reactive product and uniform film formation, concavity embedment and fluidity.
- 50 [0022] Accordingly, it can be considered that H_2O and OH radical adsorbed to the surface of the base film should be removed therefrom prior to a film formation so as to make the surface of the base film hydrophobic and then the film formation should be performed before the hydrophobic nature of the surface of the base film is not lost.
- 55 [0023] It has been known that, in a plasma irradiation treatment among the conventional modification treatments for the film-forming surface of the substrate, the hydrophobic nature of the surface of the SiO_2 film can be maintained for about one week even if the film is left in the clean room under a condition that the film is exposed to the air. In this case, it is estimated that, moisture and the like in the surface of the base film are removed therefrom by the plasma irradiation and the heat, and that a state where a dangling bond of Si in the surface of the SiO_2 film is terminated in

an atom of oxygen is created, as is represented by a Chemical Formula 1 below.

[Chemical formula 1]

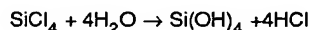


[0024] On the other hand, it is considered that the dangling bond of Si in the surface of the base film is terminated in -N, -NH₂, -H or the like depending on an atmosphere used in the plasma treatment. This is the reason why heat plays an important role in the plasma irradiation treatment. However, it cannot be considered that the entire surface of a narrow and deep concavity can be treated by plasma in the above describe manner without exception.

[0025] FIGS. 4A and 4B shows the schematic state of the surface of the SiO₂ film. FIG. 4A shows the state of the film-forming substrate immediately after formation of the SiO₂ film. The upper and lower drawings of FIG. 4B show the state of the film-forming surface of the substrate after the surface was left in the air. These two drawings show the state where the dangling bond of Si is bonded with a hydroxyl radical (OH), and the state where the dangling bond of Si is bonded with an molecule of water (H₂O), respectively.

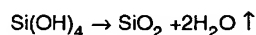
[0026] An invention has been already made by the inventor of the present invention, in which using a halide of silicon, for example, SiCl₄ (silicon tetrachloride) which exhibits the highest reactivity, is applied to the surface of the SiO₂ film. As is represented by a Chemical Formula 2 below, by exposing the film-forming surface of the substrate to SiCl₄, HCl is generated thus producing silanol.

[Chemical Formula 2]



[0027] The reaction between the SiO₂ film and SiCl₄ shows very strong dehydration. At this time, if a temperature of a reaction portion is 100 °C or higher during the reaction period, silanol gradually decomposes into SiO₂ as shown in a Chemical Formula 3, and H₂O is removed from the reaction portion of the surface of the SiO₂ film.

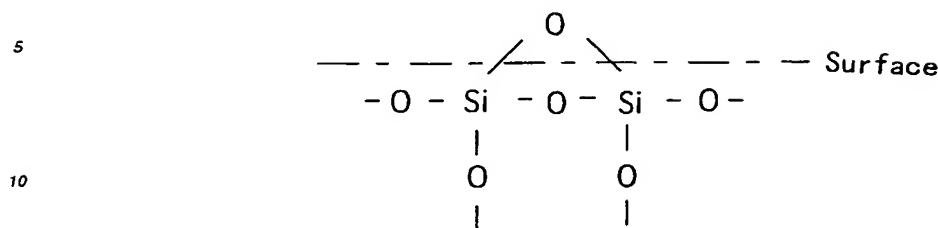
[Chemical Formula 3]



[0028] Furthermore, the following can be assumed. Cl of SiCl₄ reacts with -OH and generates HCl, and creates simultaneously an Si-Cl bond by substituting for O, so that Si in the surface of SiO₂ is terminated in Cl.

[0029] In the film-forming surface of the substrate thus treated, if a temperature of the film-forming substrate is 100 °C or higher, water and HCl are released from the system. Thus an Si-O bond or Si-Cl bond is left in the film-forming surface of the substrate as shown in a Chemical Formula 4 below.

[Chemical Formula 4]

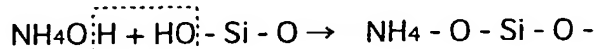


[0030] That is, the film-forming surface of the substrate will be chlorinated. With chlorination, the film-formation surface of the substrate shows a hydrophobic nature. As a result, it was found that the base surface dependency is deleted for film formation by CVD method using the High O₃/TEOS reactant gas.

[0031] In the present invention, excellent wettability can be provided to the film-forming surface of the substrate by using the modification substance which has active nitrogen and a hydrophilic nature, instead of using a halide of silicon typified by SiX₄ or a compound thereof, and by allowing the modification substance to adsorb to the film-forming surface of the substrate.

[0032] Furthermore, the modification substance of the present invention has a function of dehydrating the film-forming surface of the substrate by reacting with H₂O or the OH radical attached to the film-forming surface of the substrate. In the case where a wafer is immersed in, for example, ammonia water having the concentration of 30% for an hour, the modification substance of the present invention in ammonia water reacts with the OH radical on the surface of the SiO₂ film to form H₂O and removes H₂O by its dehydrating function. With the reaction and the function described above, the state represented by the Chemical Formula 5 below is created and the dangling bond of Si in the surface of the SiO₂ film is terminated in NH₄O⁻.

[Chemical Formula 5]



[0033] The treated surface of the SiO₂ film was maintained as it was after water cleaning and drying. Then, in formation of a film by the CVD method using the High O₃/TEOS reactant gas, the base surface dependency could be deleted completely, and the formation of the film could be performed, maintaining the same film formation rate and the same quality of the film as that in film formation on the silicon surface. Additionally, it is assumed that, H₂O was furthermore removed after the surface was dried and that the structure of the surface took a form represented by the Chemical Formula 6 below. The process is shown in FIGS. 4C to 4E.

[Chemical Formula 6]



[0034] Furthermore, when the wafer in which the SiO₂ film is the film-forming surface of the substrate was exposed

to an NH_3 gas, the same effect as that in the case where the wafer was exposed to ammonia water was obtained. That is, the wafer was placed in a chamber, the temperature was increased to 100°C , the NH_3 gas was directly fed into the chamber and the wafer was treated for one minute. Then it was found that the base surface dependency on the film-forming surface of the substrate was completely deleted from the surface of the SiO_2 film. In this case, it is assumed that there was the following mechanism. The OH radical on the film-forming surface of the substrate is bonded to an H of NH_3 and removed as H_2O , and instead of the OH radical, remaining NH_2 bonds to the dangling bond of Si in the film-forming surface of the substrate.

[0035] The modification gases that can be used in the present invention will be listed below.

10 (Modification Substances)

[0036] In the present invention, such compounds as ammonia (NH_3), hydrazine ($(\text{NH}_2)_2$) and other compounds having an amino radical ($-\text{NH}_2$) as their base are used as modification substances.

15 (a) Ammonia (NH_3)

Ammonia is gas at ordinary temperatures. An aqueous solution thereof is ammonia water. It should be noted that the ammonia water is called ammonium hydroxide and that the ammonia water may be referred to as NH_4OH in the following description for the sake of convenience.

Furthermore, substances represented by a chemical formula $\text{NH}_n\text{R}_{4-n}(\text{OH})$ (where, n is an integer of 1 to 4 and R is an alkylene radical) can be used as the derivatives of ammonium hydroxide. For example, when $n=2$ and $\text{R}=\text{CH}_3$ in the above chemical formula, the substance is dimethyl ammonium hydroxide.

20 (b) Hydrazine ($(\text{NH}_2)_2$)

Hydrazine is liquid at ordinary temperatures. ($(\text{NR}_2)_2$) (where, R is any of alkylene radicals such as CH_3 , C_2H_5 , C_3H_7 , aryl radicals including a benzene ring and the like) can be used as the derivatives of hydrazine. It should be noted that when R is CH_3 , the substance is dimethyl hydrazine ($\text{N}(\text{CH}_3)_2$).

25 (c) Amine

An amine is a compound having an organic radical (R), for example, the alkylene radical, aryl radical including the benzene ring or the like, as a substitute for an atom of hydrogen in ammonia. The amine belongs to an organic alkali.

30 $\text{NR}_n\text{H}_{3-n}$ (where, n is an integer of 1, 2 or 3) and the like can be used as the amines.

(d) Amino compound

An amino compound is a compound having an amino radical ($-\text{NH}_2$).

35 [0037] As the amino compounds, an amino acid (RNH_2COOH), amino benzene (aniline) ($\text{C}_6\text{H}_5\text{NH}_2$), aminophenol ($\text{C}_6\text{H}_4\text{NH}_2\text{OH}$) and aminobenzenesulfonic acid ($\text{C}_6\text{H}_4\text{SO}_3\text{H}\text{NH}_2$) and the like can be used. R is an organic radical of an alkylene radical, aryl radical including a benzene ring or the like.

[0038] These modification substances (a) to (d) have the following characteristics in common. That is, these substances have active atoms of nitrogen and the hydrophilic nature, adhere to the surface of the SiO_2 film and exhibit the excellent wettability. Accordingly, the modification substances used for the present invention are not limited to the examples (a) to (d) given above and any substances having the above-described characteristics can be used.

(Equipment for modification treatment/film formation apparatus)

45 [0039] FIGS. 8A and 8B are schematic constitutions showing an apparatus for a modification treatment according to the modification method for the film-forming surface of the substrate of the embodiment of the present invention.

[0040] As is shown in FIGS. 8A and 8B, a container 21 contains a modification substance 22. The substance 22 is a liquid such as ammonia water. The film-forming substrate 102 is immersed in the liquid so as to allow the film-forming surface of the substrate 102 to be modified.

50 [0041] FIG. 9 is a schematic constitution view showing a cold wall type modification treatment/CVD system. The system can perform both of the modification treatment and formation of a film by the CVD method.

[0042] A reaction chamber 61 (chamber) made of stainless is equipped with a susceptor 62 for holding a silicon wafer 102. The susceptor 62 contains a heater (heating means) for heating the silicon wafer.

55 [0043] The reaction chamber 61 is furthermore equipped with a pipe 68a and a gas dispersion plate 64 connected to one end of the pipe 68a. The pipe 68a introduces the gas to be used for forming a film (hereinafter referred to as deposition gas) such as a mixed O_3/TEOS gas or the gas to be used for modifying the film-forming surface of the base (hereinafter referred to as modification gas), the gas being supplied from gas supply means 63. The gas dispersion plate 64 applies the deposition gas or modification gas to the silicon wafer 102 placed on the susceptor 62. An air exhaustion apparatus 65 for adjusting a pressure in the reaction chamber 61 is connected to the reaction chamber 61.

[0044] The gas supply means 63 is composed of modification gas supply means 66, deposition gas supply means 67, pipes 68b and 68c and a switching valve 69 (switching means).

[0045] The modification gas supply means 66 supplies the modification gas to the inside of the reaction chamber 61 when the film-forming surface of the substrate is subjected to the modification treatment, and the deposition gas supply means 67 supplies the deposition gas after modification of the film-forming surface of the substrate.

[0046] The pipes 68b and 68c are connected to these two gas supply equipment 66 and 67, respectively, and the pipes 68b and 68c are furthermore connected to the pipe 68a reaching the inside of the reaction chamber 61. The switching valve 69 is attached to a portion at which these three pipes 68b, 68c and 68a are connected together. The switching valve 69 switches channels for the gases in the manner that the switching valve 69 opens one of the channels for introducing the modification gas from the pipe 68b to the pipe 68a or the other channel for introducing the deposition gas from the pipe 68c to the pipe 68a. The modification gas and deposition gas are selectively introduced to the inside of the reaction chamber 61 through the pipe 68a by switching the channels with the switching valve 69.

[0047] In the modification gas supply means 66, the modification gas is supplied in any of the following three ways.

- 1) The gas is supplied as it is from a gas bomb.
- 2) A liquid modification substance is evaporated and then supplied as it is.
- 3) The evaporated modification substance is supplied in the state where it is contained in an N_2 , H_2 or Ar gas as a carrier gas.

[0048] The modification gas supplied from the modification supply means 66 is introduced to the inside of the reaction chamber 61 through the pipe 68b.

[0049] In the embodiment of the present invention, although the same chamber 61 was used for the modification of the film-forming surface of the substrate as well as for formation of the O_3 /TEOS SiO_2 film, separate chambers may be used.

[0050] Furthermore, either of a single wafer process chamber or a batch process system of reactor type may be used as the reaction chamber 61.

[0051] Still furthermore, in the embodiment of the present invention, a cold wall type reactor was used, however, a hot wall type reactor may be used. FIG. 10 shows the hot wall type reactors. FIG. 10A shows a horizontal type reactor and FIG. 10B shows a vertical type reactor. Either of the two types may be used.

[0052] In the case where the hot wall type reactor is used, the heater or an infrared heater placed near the chamber can be used as heating means.

(Method for modifying a film-forming surface of a substrate and method for manufacturing a semiconductor device using the same)

[0053] Next, the method for modifying the film-forming surface of the substrate and the manufacturing method for forming the semiconductor device using the same according to the present invention will be described below.

[0054] FIGS. 3A to 3C are cross-sectional view showing the method for modifying the film-forming surface of the substrate and the manufacturing method for forming the semiconductor device using the same according to the embodiments of the present invention. FIG. 4A is a cross-sectional view showing the state of a surface of a thermal oxide film 12 immediately after formation of the thermal oxide film 12 used as the film-forming surface of the substrate (i.e., the film-forming surface of the substrate 12a). The upper and lower drawings of FIG. 4B are cross-sectional views showing the state of the thermal oxide film 12 before it was modified. FIGS. 4C to 4E are drawings showing a process of the reaction between the thermal oxide film 12 and ammonia water, which was used as the modification substance, in the surface of the thermal oxide film 12. The apparatus shown in FIGS. 8A and 8B was used as the one for the modification treatment.

[0055] First, a semiconductor substrate 11 made of silicon is placed in an oxidation reactor and heated to about 1100 °C in an atmosphere of oxygen. As is shown in FIG. 3A, the surface of the semiconductor substrate 11 is oxidized, so as to form a thermal oxide film 12 made of SiO_2 . This thermal oxide film 12 constitutes the film-forming substrate as the uppermost layer, that is, the surface of the film 12 is now the film-forming surface 12a of the substrate. Thus, the film-forming substrate 102 is composed of the semiconductor substrate 11 and the thermal oxide film 12. It should be noted that wirings may be formed on the thermal oxide film 12. In this case, the film-forming substrate 102 includes the wirings.

[0056] It should be also noted that the step of forming the above base layer, which is the thermal oxide film 12, may be performed by a plasma CVD method, a reduced pressure CVD method or the like.

[0057] It is assumed that, as shown in FIG. 4A, the dangling bond of Si exists in the surface of the thermal oxide film 12 immediately after formation thereof. However, it is assumed that, as is shown in the upper drawing of FIG. 4B, the surface of the thermal oxide film 12 is normally in the state of hydration by contacting with water-laden air where an

Si-OH bond is created. Alternatively, as is shown in the lower drawing of FIG. 4B, the surface of the thermal oxide film 12 may be in the state where an Si-H₂O bond is created. Whichever state it may be, it is assumed that the surface of the thermal oxide film 12 has the hydrophilic nature (hydrophilicity).

[0058] Next, as is shown in FIGS. 8A and 8B, the film-forming substrate 102 is immersed in ammonia water (i.e. the modification substance) 22. It can be assumed that the reaction described below is taking place between the thermal oxide film 12 and ammonia water 22 while the film-forming substrate 102 is in the ammonia water.

[0059] The reaction will now be described, taking the case where the dangling bond of Si is terminated in -OH in the surface of the thermal oxide film 12.

[0060] First, the surface of the heated thermal oxide film 12 is exposed to NH₄OH. In the surface of the heated thermal oxide film 12, as is shown in FIG. 4C, -OH of the Si-OH bond and -H in NH₄OH are bonded together, so as to generate H₂O. With this reaction, -H is removed from NH₄OH, so as to leave NH₄O on the bond of Si in the surface of the thermal oxide film 12. The resultant H₂O is released from the reactive region on the surface of the thermal oxide film 12.

[0061] Next, the film-forming surface 12a of the substrate 102 is dried by heating or other means. As is shown in FIG. 4E, H₂O is removed from NH₄O bonded to Si in the surface of the thermal oxide film 12, so as to leave NH₂. As a result, the surface of the thermal oxide film 12 shows the hydrophobic nature (hydrophobicity).

[0062] In the case where Si in the surface of the thermal oxide film 12 is bonded to H₂O, it is assumed that the surface of the thermal oxide film 12 exhibits the hydrophobic nature by way of the following step. The reaction takes place between NH₄OH and H₂O, followed by the similar process to that in the case where the Si-OH bond exists in the surface of the thermal oxide film 12. H₂O bonded to Si in the surface of the thermal oxide film 12 is substituted by NH₂.

[0063] Subsequent to the above-described modification treatment, the supply of the modification gas is stopped, and the High O₃/TEOS gas, as the deposition gas for use in film formation, is fed from the deposition gas supply means 67 into the reaction chamber 61.

[0064] Then, the film-forming substrate 102 is heated to 400 °C to cause a thermal reaction between O₃ and TEOS. The reactive state is maintained for a predetermined time. After the passage of the predetermined time, as is shown in FIG. 3C, a High O₃/TEOS CVD SiO₂ film is formed on the thermal oxide film 12.

[0065] In the case where the system as shown in FIG. 9 which is used for both of the modification treatment and film formation, the steps of the modification treatment and film formation are performed as the following.

[0066] First, the thermal oxide film 12 is formed in the same manner as described above. Here, an assumption is made that the state of the film-forming surface 12a of the substrate 102 is the same as that shown in the upper or lower drawing of FIG. 4B.

[0067] Next, as is shown in FIG. 9, the silicon wafer 1 is placed on the susceptor 62 in the reaction chamber 61, and is heated to at least 100°C by the heater built-in in the susceptor 62. Then, the NH₃ gas (i.e. the modification gas) is supplied from the modification gas supply means 66 to the reaction chamber 61. The modification gas is applied to the surface of the thermal oxide film 12 formed on the semiconductor substrate 11.

[0068] It can be assumed that the reaction similar to that shown in FIGS. 4C to 4E is taking place between the thermal oxide film 12 and the modification gas on the surface of the thermal oxide film 12 while the gas is being applied. In other words, it can be assumed that there is a reactive mechanism. That is, an OH radical in the film-forming surface 12a of the substrate 102 is bonded to H of NH₃, so as to be removed as H₂O, and remaining NH₂ substitutes for the OH radical, so that NH₂ is bonded to the dangling bond of Si in the film-forming surface 12a of the substrate 102.

[0069] Since the modification gas containing the active nitrogen is used in the above-described modification treatment performed on the film-forming surface 12a of the substrate 102, it is possible to move immediately to the next step, which is the step of forming a film, without performing any treatment, such as cleaning and the like, on the surface of the thermal oxide film 12 after the above-described modification treatment. That is, subsequent to the above-described modification treatment, the supply of the modification gas is stopped and the mixed O₃/TEOS gas, as the deposition gas, is fed from the deposition gas supply means 67 to the inside of the reaction chamber 61.

[0070] Then, under the same conditions as described above, the High O₃/TEOS CVD SiO₂ film 13 is formed on the film-forming substrate 102.

[0071] Thus, in the present invention, since film formation is performed using O₃/TEOS reactant gas after modifying the surface of the thermal oxide film 12 into hydrophobicity, the fluidity, flatness, concavity embedment and step coverage exhibited by the formed High O₃/TEOS CVD SiO₂ film 13 can be enhanced.

[0072] In particular, since the modification gas containing the active element of nitrogen is used as the modification gas, the effects of modification can be maintained. In fact, the High O₃/TEOS CVD SiO₂ film 13 was formed on the surface of the thermal oxide film 12 after exposing the surface of the thermal oxide film 12 to air for 24 hours after modifying the film-forming surface 12a of the substrate 102. The fluidity, flatness, concavity embedment and step coverage exhibited by the formed High O₃/TEOS CVD SiO₂ film 13 were still maintained.

(First Embodiment)

[0073] Now, the first embodiment will be described with reference to FIG. 5. In this embodiment, the modification method of the present invention is applied to the film-forming surface of the substrate 102 in which the wirings 14a and 14b made of aluminum or the like are formed on the thermal oxide film 12.

[0074] In FIG. 5, the same elements as the elements shown in FIG. 3 are denoted by the same reference numerals.

[0075] As is shown in FIG. 5, the semiconductor substrate 11 made of silicon was heated to 1100 °C, so as to form the thermal oxide film 12 made of SiO₂ having thickness of about 300 nm on the surface thereof. The thermal oxide film 12 was thus prepared to be used as the base layer on which another film is to be formed.

[0076] Next, the film-forming surface of the substrate 102 was modified by exposing the film-forming surface of the substrate 102 to the modification gas. As one of the conditions for modifying the surface of the base, the NH₃ gas (modification gas) was used. The NH₃ gas was allowed to contact with the film-forming surface of the substrate 102.

[0077] Next, the High O₃/TEOS CVD SiO₂ film 13 of about 500 nm in thickness was formed on the modified surface of the base layer 12. As one of the conditions for forming the High O₃/TEOS CVD SiO₂ film 13, the concentration of ozone contained in the deposition gas, which was consisted of the mix O₃/TEOS gas, was set at "a high concentration", that is, 5 % of O₃ in O₂. The film-forming substrate 102 was heated to 400 °C.

[0078] As shown in FIG. 5, the modification treatment using the method for modifying the film-forming surface of the base according to the first embodiment was performed, and then the High O₃/TEOS CVD SiO₂ film 13 having the smooth surface free from voids was formed by the CVD method using the High O₃/TEOS deposition gas.

[0079] As described above, when the surface modification for the uneven film-forming surface 12a of the substrate 102 having wirings 14a and 14b or the like was performed by using the modification gas containing the active element of nitrogen, the High O₃/TEOS CVD SiO₂ film 13 can be formed so as to completely fill the concave portion between the wirings 14a and 14b and so as to give the excellent step coverage at the steps of the wirings 14a and 14b.

(Second Embodiment)

[0080] Now, the second embodiment will be described with reference to FIG. 6.

[0081] In this embodiment, the present invention is applied to the film-forming surface of the substrate having the narrow and deep trench therein. For comparison, a comparative example is shown in FIG. 7, in which a film was formed on the "base layer" which had not been subjected to the modification method of the present invention.

[0082] FIG. 6 is a drawing showing a cross-sectional view of the High O₃/TEOS CVD SiO₂ film 13 formed after performing the modification treatment on the film-forming surface of the substrate. FIG. 7 is a drawing showing a cross-sectional view of a High O₃/TEOS CVD SiO₂ film 13a formed without performing the modification treatment. In FIGS. 6 and 7, the same elements as the elements shown in FIG. 3 are denoted by the same reference numerals.

[0083] As is shown in FIG. 6, the trench of about 0.1 μm in width and about 0.6 μm in depth was formed in the surface of the semiconductor substrate 11 made of silicon. The thermal oxide film 12 made of SiO₂ was formed on the surface of the semiconductor substrate 11 under the same conditions as in the first embodiment. The thermal oxide film 12 is thus prepared as the base layer. Then, the High O₃/TEOS CVD SiO₂ film 13 was formed on the surface of the base layer. Then, the concavity embedment and step coverage exhibited by the High O₃/TEOS CVD SiO₂ film 13 was examined.

[0084] Unlike the first embodiment, ammonia water was used as the modification substance. The film-forming substrate 102 was immersed therein. The temperature of the ammonia water was set in a range 50 to 80 °C and a time for immersion was set at about 10 minutes.

[0085] As a part of the conditions for forming the O₃/TEOS CVD SiO₂ film 13, the concentration of ozone and the heating temperature for the film-forming substrate 102 were set at the same value as in the first embodiment.

[0086] From FIG. 6, it can be seen that the O₃/TEOS CVD SiO₂ film 13 having the flat surface was formed on the sample, which had been subjected to the modification treatment using the method for modifying the surface of the film on which another film is to be formed according to the embodiment of the present invention.

[0087] In contrast to the above, from FIG. 7, it can be seen that, when the O₃/TEOS CVD SiO₂ film 13 was formed without performing the modification treatment on the surface of the base, the surface of the film 13 was not flat but wavy with a void therein.

[0088] As described above, in the case where the surface of the base layer 12 having a very narrow trench 15 is modified by using the modification gas containing active nitrogen, the embedment and step coverage of the trench 15 by the High O₃/TEOS CVD SiO₂ film 13 can be enhanced.

[0089] It should be noted that the High O₃/TEOS CVD SiO₂ film 13 is used as the insulating film to be formed on the film-forming surface 12a in the above embodiments, however, the insulating films formed by combination of other silicon-containing organic compounds, for example, alkoxysilane, siloxane and the like, and oxidation gases may be used.

[0090] Furthermore, as the insulating film to be formed on the film forming surface 12a, any of a PSG (Phosphosilicate glass) film, a BSG (Borosilicate glass) film and a BPSG (Borophospho-silicate glass) film may be used other than the SiO₂ film. For the deposition gas used to form the PSG film, a mixed O₃-TEOS-TMP (Trimethylphosphite: P(OCH₃)₃) gas or a mixed O₃-TEOS-TMOP (Trimethylphosphate: PO(OCH₃)₃) gas may be used. For the deposition gas used to form the BSG film, a mixed O₃-TEOS-TMB (Trimethylborate: B(OCH₃)₃) gas may be used. For the deposition gas used to form the BPSG film, a mixed O₃-TEOS-TMB-TMP gas or a mixed O₃-TEOS-TMB-TMOP gas may be used.

[0091] Furthermore, in the above embodiments, the modification treatment is performed using the liquid or gas without adding acceleration, however, application of ultrasonic and/or megasonic to the substrate 102 during the modification treatment may further enhance the effects of modification.

[0092] As described above, according to the modification method of the present invention, since the film-forming surface of the substrate on which the insulating is to be formed has been modified by allowing ammonia, hydrazine, the amine, the amino compounds, gaseous derivatives thereof or liquids thereof to contact with the film-forming surface of the substrate before formation of the film, the dangling bond of silicon in the film-forming surface of the base can be terminated in NH₄O⁻ or NH₂⁻.

[0093] Therefore, the surface dependency on the base in formation of the film thereon can be deleted.

[0094] In particular, since the neutral gas is used as the modification substance, the modification substance covers the surface of the narrow and deep concavity and the surface dependency on the surface of the concavity can be deleted.

[0095] Accordingly, in the case where the film is formed, by the thermal CVD method, on the film-forming surface of the base the surface dependency has been deleted on the surface thereon, the interlayer insulating film and/or cover insulating film, which are excellent in quality and free of rough surfaces and voids, can be formed without bringing about reduction of film deposition rate. It is also possible to fill almost completely the narrow and deep concavity. Micronization and high integration of the semiconductor device can be therefore realized.

[0096] Although the preferred embodiment of the present invention has been described in detail, it should be understood that various changes, substitutions and alternations can be made therein without departing from spirit and cope of the invention as defined by the appended claims.

Claims

1. A method for modifying a film-forming surface of a substrate comprising the step of:
modifying said film-forming surface (12a) of the substrate (102) by allowing one at least selected from the group consisting of ammonia, hydrazine, an amine, gases thereof and aqueous solutions thereof to contact with said film-forming surface (12a) of the substrate (102) before forming an insulating film (13) on said film-forming surface (12a) of the substrate (102).
2. The method according to claim 1, wherein said film-forming surface (12a) of the substrate (102) is the surface exposing at least one of a silicon oxide film (12) and a silicon nitride film.
3. The method according to claim 2, wherein said film-forming surface (12a) of the substrate (102) is the surface exposing at least one of a semiconductor and wirings (14a, 14b) in addition to at least one of said silicon oxide film (12) and said silicon nitride film.
4. The method according to claim 2, wherein said silicon oxide film (12) is formed by the thermal oxidation method, thermal CVD method or plasma enhanced CVD method.
5. The method according to claim 2, wherein said silicon nitride film is formed by the thermal CVD method or plasma enhanced CVD method.
6. The method according to claim 1, wherein said amine is the one having a chemical formula NR_nH_{3-n} (R: an organic radical).
7. The method according to claim 1, wherein said amino compound is the one having a chemical formula RNH₂ (R: an organic radical).
8. A method for manufacturing a semiconductor device comprising the steps of:

modifying a film-forming surface (12a) of a substrate (102) by allowing at least one selected from the group

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consisting of ammonia, hydrazine, an amine, gases thereof and aqueous solutions thereof to contact with said film-forming surface (12a) of the substrate (102) on which a film is to be formed; and forming an insulating film (13) on the modified film-forming surface of the substrate (102).

- 5 9. The method according to claim 8, wherein said insulating film (13) is a silicon-containing insulating film formed by a thermal CVD method using a reactant gas containing an ozone-containing gas and Tetra-Ethyl-Ortho-Silicate.

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FIG. 1

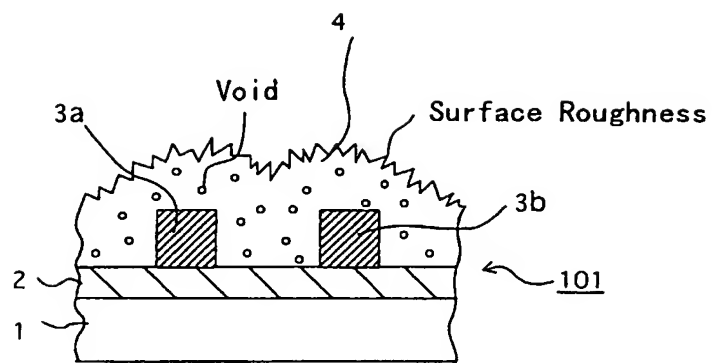


FIG. 2A

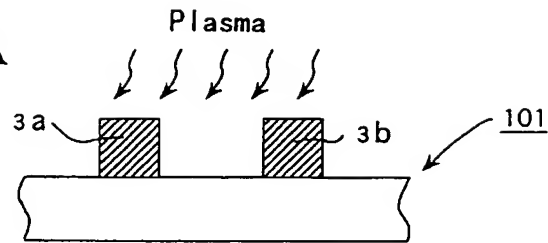


FIG. 2B

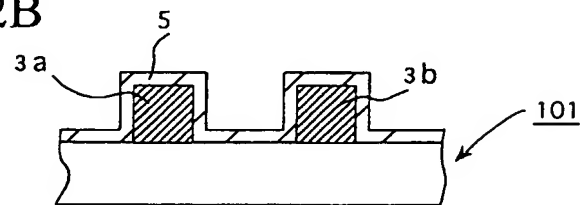


FIG. 2C

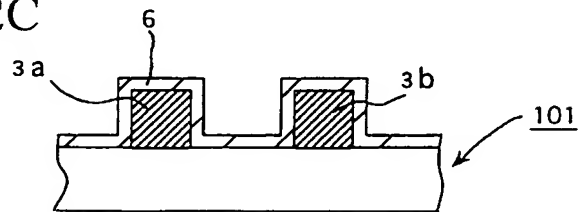


FIG. 2D

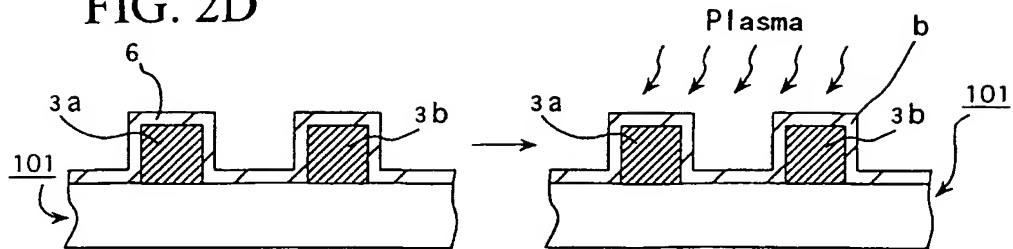


FIG. 3A

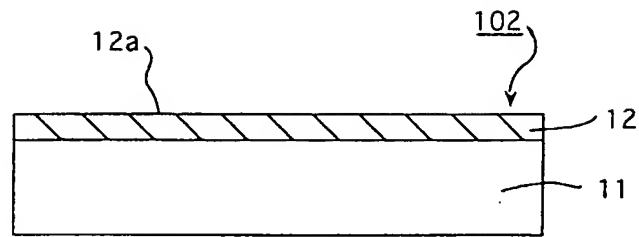


FIG. 3B

Surface Modification Treatment by Modification
Substances Containing Active Nitrogen

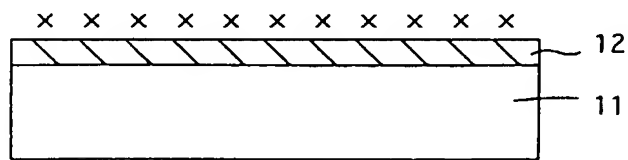
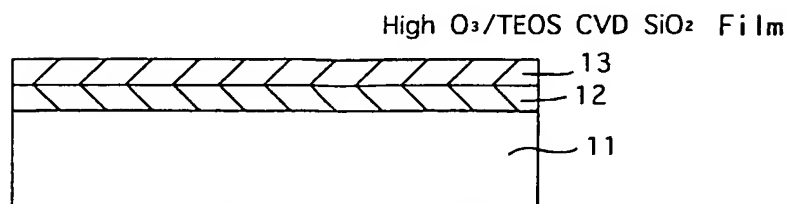
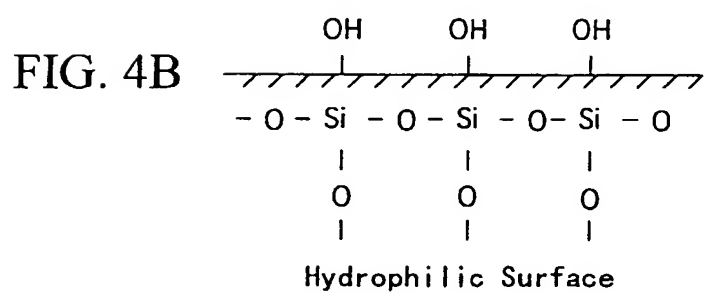
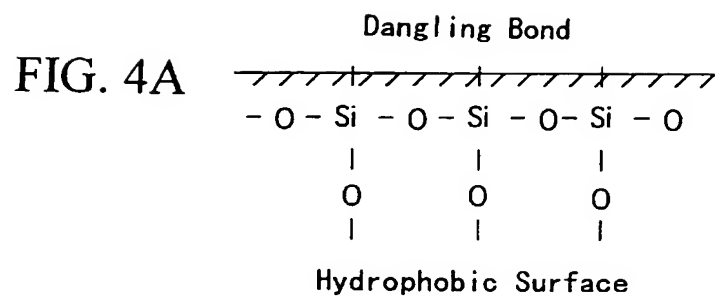


FIG. 3C





or

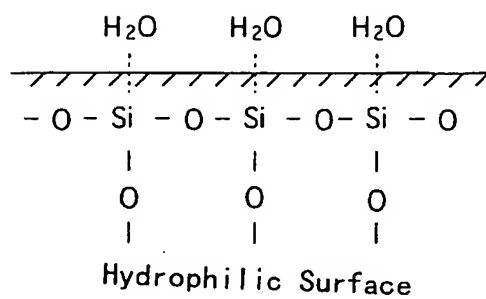


FIG. 4C

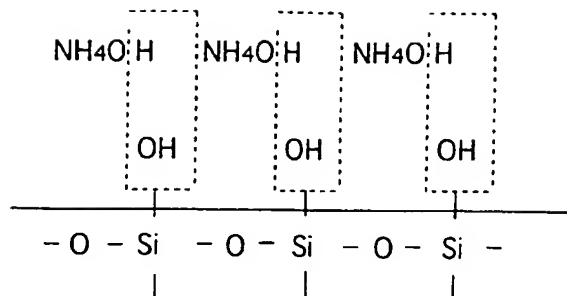


FIG. 4D

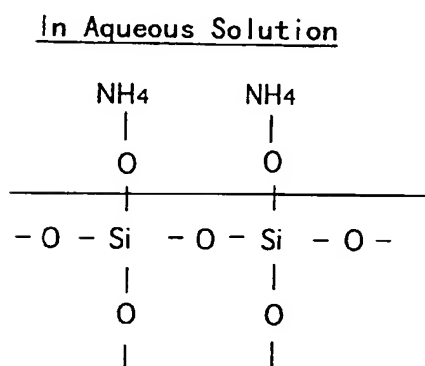


FIG. 4E

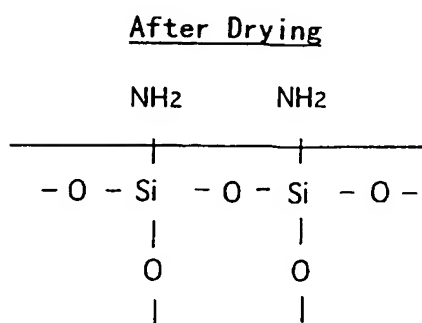


FIG. 5

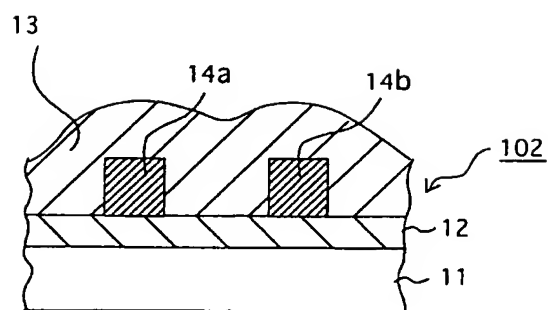


FIG. 6

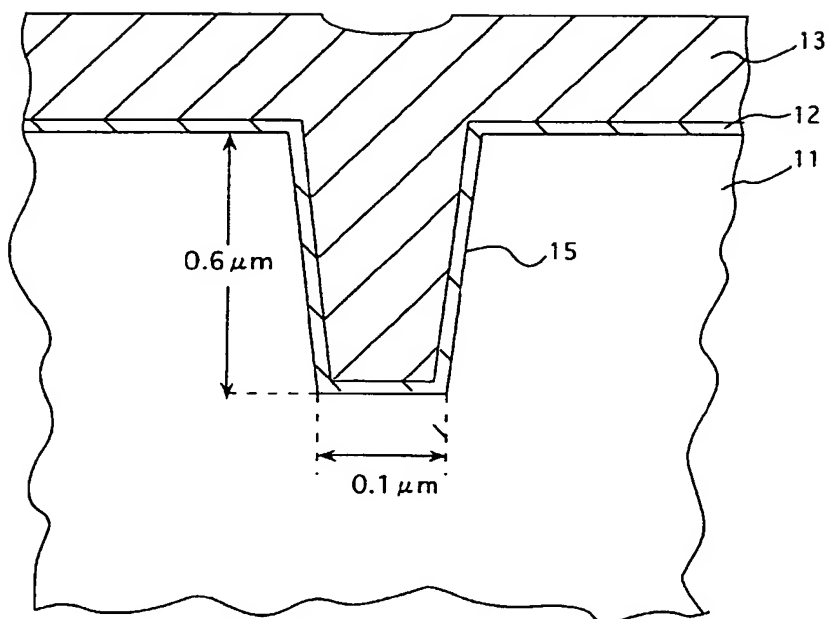


FIG. 7

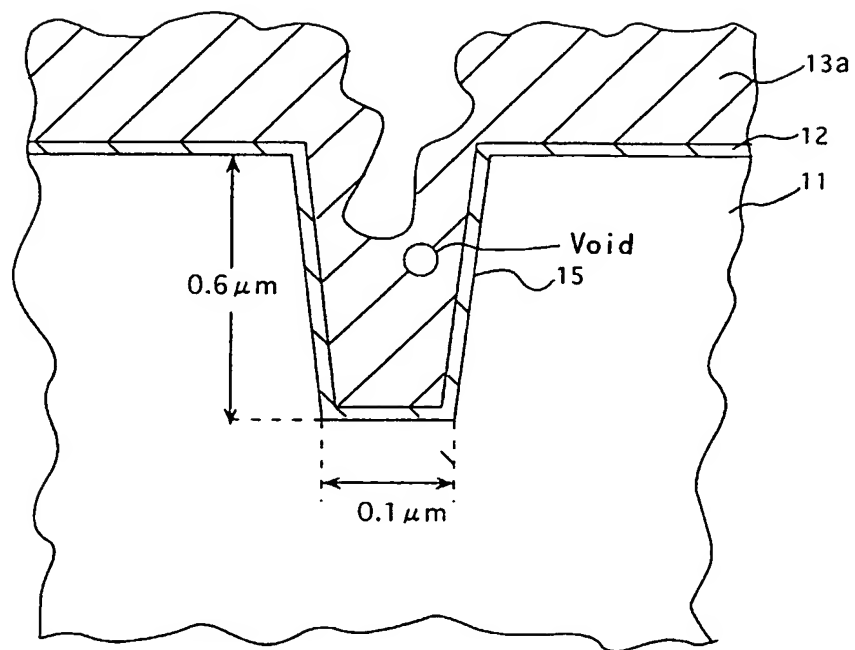


FIG. 8A

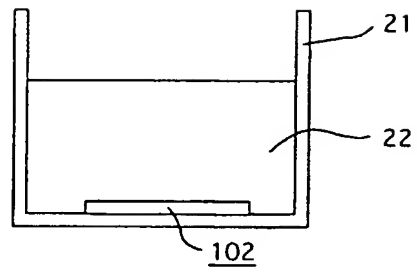


FIG. 8B

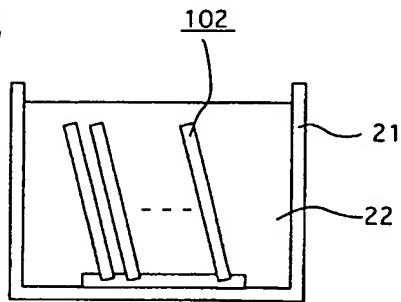


FIG. 9

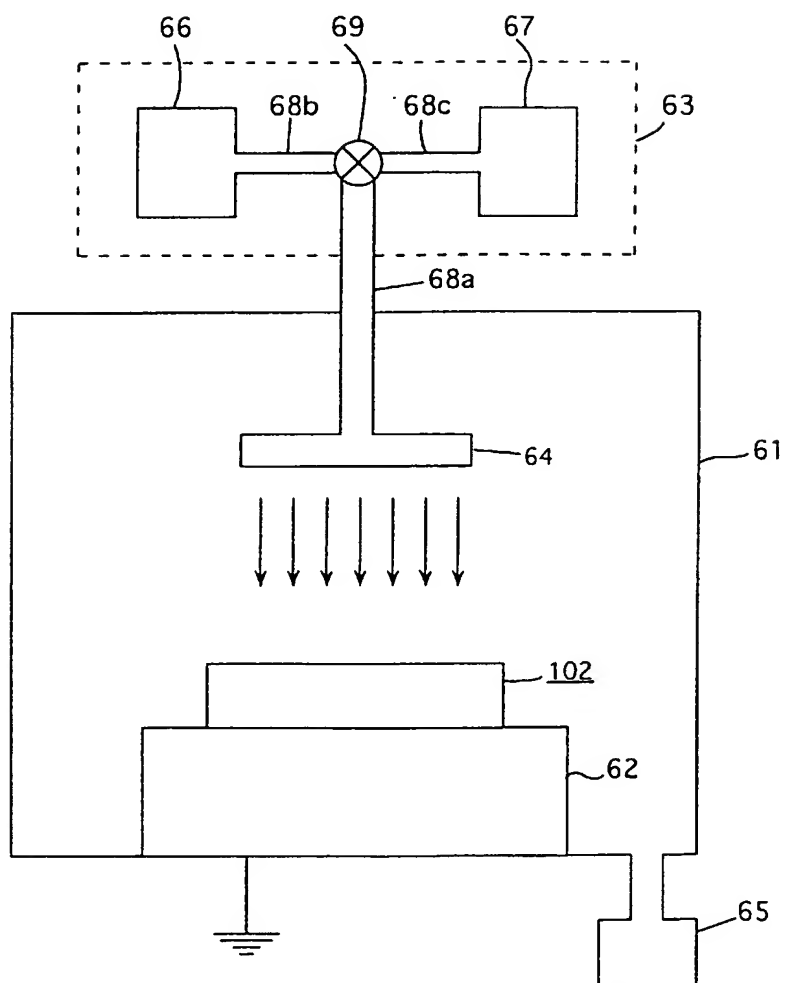


FIG. 10A

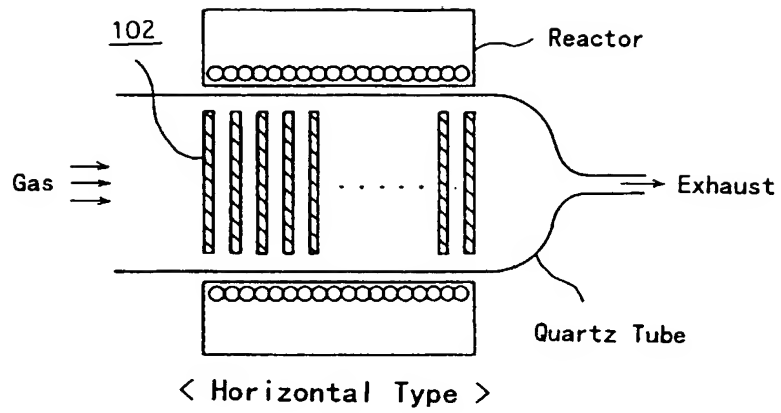
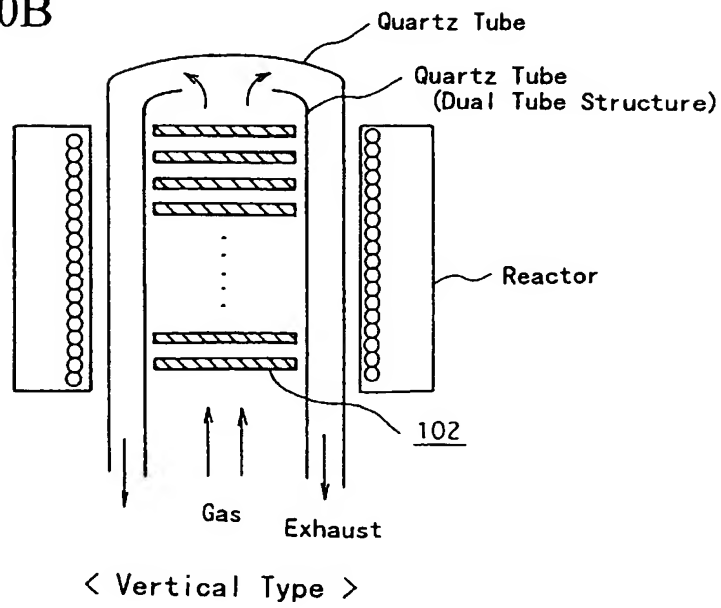


FIG. 10B





European Patent
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EUROPEAN SEARCH REPORT

Application Number
EP 99 12 3923

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X	US 5 656 337 A (PARK IN-SEON ET AL) 12 August 1997 (1997-08-12) * column 6, line 23 - line 64 *	1-5,8,9	H01L21/316 H01L21/306 C23C16/40 C23C16/02
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Place of search BERLIN		Date of completion of the search 14 June 2000	Examiner Le Meur, M-A
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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**ANNEX TO THE EUROPEAN SEARCH REPORT
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